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Beneath the Baselines: Detecting Molecular Emission from Submillimeter Galaxies with the GBT

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Abstract. We report the first detection of a submillimeter galaxy (SMG) in CO(1→0) emission using the GBT. We identify a line with $\Delta v_{\rm FWHM} \sim 1000\,{\rm km\,s^{-1}}$ in the 1 cm spectrum of SMM J13120+4242 at $z = 3.408$, which is significantly greater than the width of the previously detected CO(4→3) line. If the observed CO(1→0) line profile arises from a single object and not several merging objects, the CO(4→3)/CO(1→0) brightness temperature ratio of ~ 0.26 suggests $n({\rm H_2}) > 10^3\,{\rm cm^{-3}}$ and the presence of sub-thermally excited gas. The 10σ integrated line flux implies a cold molecular gas mass $M({\rm H_2}) \sim 10^{11}\,M_\odot$, comparable to the dynamical mass estimate and four times larger than the H_2 mass found from the CO(4→3) line. While our observations confirm that this SMG is massive and highly gas-rich, they also suggest that $J_{\rm upper} > 3$ transitions of CO may not accurately trace cold, diffuse molecular gas in SMGs.

1. Introduction

Studies of molecular gas emission provide the crucial mass and dynamical information needed to evaluate submillimeter-selected galaxies (SMGs) in the context of hierarchical galaxy formation and evolution. The total intensity of molecular emission indicates the mass of gas that is available to fuel future star formation, and the ratios of the intensities of emission from different rotational transitions reveal the temperature and density of the gas, suggesting how the gas is being consumed. Even though CO emission from SMGs is near currently achievable detection limits, several surveys (e.g., Neri et al. 2003; Greve et al. 2005; Tacconi et al. 2006) have successfully detected $J > 3$ CO($J \rightarrow J-1$) transitions in SMGs, finding that SMGs are massive (median $M_{\rm dyn} > 1.2 \times 10^{11}\,M_\odot$: Greve et al. 2005), gas-rich (median $M({\rm H_2}) = 3.0 \times 10^{10}\,M_\odot$: Greve et al. 2005), and compact (median $D < 4$ kpc: Tacconi et al. 2006), consistent with the hypothesis that SMGs are high-z counterparts of ULIRGs, possibly progenitors of large bulges or elliptical galaxies observed locally (Smail et al. 2002). All of this information derives from warm molecular gas, but we have limited knowledge of the less excited, cold molecular gas that makes up a substantial fraction by mass of the gas content of present-day galaxies (e.g., the observations of M82 of Weiß, Walter, & Scoville 2005). With a low threshold for excitation, requiring $n({\rm H_2}) \sim 10^2\,{\rm cm^{-3}}$ and $\Delta E/k \sim 5$ K, CO(1→0) emission ($\nu_{\rm rest} = 115.271$ GHz) is the most representative tracer of the metal-enriched molecular gas mass in galaxies because it is sensitive to cold, diffuse gas that may dominate the mass. Observations of CO($1 \rightarrow 0$) in SMGs are thus complementary to previous studies of $J > 3$ gas.

Previously, studies of CO(1→0) emission from high-z galaxies have been carried out with the Very Large Array (VLA) (Papadopoulos et al. 2001; Carilli et al. 2002; Greve, Ivison, & Papadopoulos 2004). The Robert C. Byrd Green Bank Telescope (GBT) exceeds the current capabilities of the VLA in instantaneous spectral bandwidth (800 MHz maximum per spectrometer bank, compared with 50 MHz at the VLA). Since high-z CO lines can be wider than the VLA bandwidth (Greve et al. 2004), and the two facilities have comparable effective collecting areas, the GBT is better suited to search for and measure accurately CO emission from SMGs.

Here we present some of the results of a GBT search for CO(1→0) emission from SMGs. Because the newly-commissioned Ka-band (26–40 GHz) receiver at the GBT is not yet available, we used the K-band (18–26 GHz) receiver for our search. The tuning range of the GBT's K-band receiver restricts our potential SMG targets to those with redshifts greater than $z \simeq 3.35$, of which there are only four with measured redshifts. We chose to target the two that also had previous CO(4→3) detections from the IRAM Plateau de Bure interferometer: SMM J09431+4700 at $z_{\rm CO} = 3.346$ (Neri et al. 2003; hereafter SMM 09431) and SMM J13120+4242 at $z_{\rm CO} = 3.408$ (Greve et al. 2005; hereafter SMM 13120).

Throughout this paper, we assume $H_0 = 70$ km s^{-1} Mpc^{-1}, $\Omega_m = 0.3$, and $\Omega_\Lambda = 0.7$.

2. Observations and Data Calibration

We searched for CO(1→0) emission from SMM 09431 and SMM 13120 with the 18–26 GHz (K-band) dual-feed receiver at the GBT on UT 2004 December 1. We utilized the position-switching "Nod" observing pattern (Vanden Bout, Solomon, & Maddalena 2004). Observing conditions were excellent through both night and day, with low atmospheric opacities ($\simeq 0.02$ nepers) and system temperatures in the range 30–50 K. Total on-source integration times were 6.0 hours for SMM 09431 and 6.2 hours for SMM 13120. The size of the main beam at the GBT at 26 GHz is 28″, so our observations are not spatially resolved. However, our observations should be representative of the average cold gas properties over the observed galaxies.

We used the GBT's Autocorrelation Spectrometer (ACS) to observe an 800 MHz spectral bandpass centered on the frequency at which the CO(1→0) line is expected to fall, based on the CO systemic redshift obtained from the previous CO(4→3) detection. The spectrometer banks were configured in low-resolution mode, providing 2048 391 kHz channels (~ 4.4 km s^{-1} at 26 GHz) for both of the two circular polarizations of each feed.

Vanden Bout et al. (2004) discuss the significant baseline curvature seen in wide-bandwidth GBT spectral data obtained over a range of elevations and timescales, despite the off-axis feed arm design of the telescope. Our GBT data are certainly affected by complex baseline shapes, since we average over ~ 6 hours of integration and 60° of elevation. To minimize the associated systematic errors, we use a variation of a traditional method of single-dish radio spectrum calibration, in which we use the two blank-sky reference (OFF) scans bracketing each on-source (ON) scan to construct an improved, interpolated OFF, separately for each polarization in each feed. We accomplish this using least-squares fitting to find values α and β for each scan such that

$$\frac{\mathrm{ON} - (\alpha\,\mathrm{OFF}_1 + \beta\,\mathrm{OFF}_2)}{\alpha\,\mathrm{OFF}_1 + \beta\,\mathrm{OFF}_2} = 0 \tag{1}$$

where OFF_1 refers to the scan prior to the ON scan, OFF_2 refers to the scan following the ON scan (all taken through the same feed). We then apply the derived values of α and β to obtain the normalized difference spectrum, for each scan, in units of antenna temperature:

$$T_{\mathrm{diff}}(\nu) = \frac{\mathrm{ON} - (\alpha\,\mathrm{OFF}_1 + \beta\,\mathrm{OFF}_2)}{\alpha\,\mathrm{OFF}_1 + \beta\,\mathrm{OFF}_2}(\alpha\,T_{\mathrm{sys1}} + \beta\,T_{\mathrm{sys2}}) \tag{2}$$

where T_{sys1} is the system temperature derived for the first OFF scan, and T_{sys2} is the system temperature derived for the second OFF scan. All of the calibration of our spectral data was accomplished with the new library of routines written in IDL, `GBTIDL`.

Periodogram analyses of each polarization of each feed were carried out for each scan as a check for possible systematic sources of spectral shape. We found that the right polarization of feed 2 nearly always showed an irregularly changing pattern of multiple large peaks between 0–0.03 MHz^{-1} (corresponding to periods > 30 MHz). This pattern of features was not found in feed 1 data, and was found in approximately half of the left polarization data from feed 2. Thus, in an effort to ensure that what appears as noise is due to random processes, we have not included any feed 2 data in the averaged calibrated spectrum. While this exclusion cuts our effective integration time in half and increases the spectral rms, it increases our confidence in the reality of any possible emission line detection by removing ripples and structure that could obscure the line.

Our calibration method produces qualitatively similar results to that used by Vanden Bout et al. (2004): sources detected with one calibration method are also detected by the other method. However, it is important to note that our method is suitable only for sources with very weak or undetectable continuum emission at $\lambda_{\mathrm{rest}} = 2.6$ mm. SEDs of SMGs (e.g., Chapman et al. 2005) predict that continuum emission from SMGs at 30 GHz is undetectable.

3. SMM J13120+4242

We focus here on the results for SMM 13120, since we do not detect SMM 09431.

SMM 13120 was identified as a source in the Hawaii Deep Field SSA13, with $S_{850\,\mu\mathrm{m}} = 6.2$ mJy. The galaxy, with an optical redshift of $z = 3.405$, is not known to be lensed, and its optical spectrum reveals AGN signatures (Chapman et al. 2005). Chapman et al. (2005) estimate a characteristic dust temperature from the radio-submm SED of $T_{\mathrm{d}} = 47$ K. CO observations have confirmed the redshift and shown SMM 13120 to be very massive in molecular gas. Greve et al. (2005) detect CO(4→3) emission with the IRAM Plateau de Bure interferometer

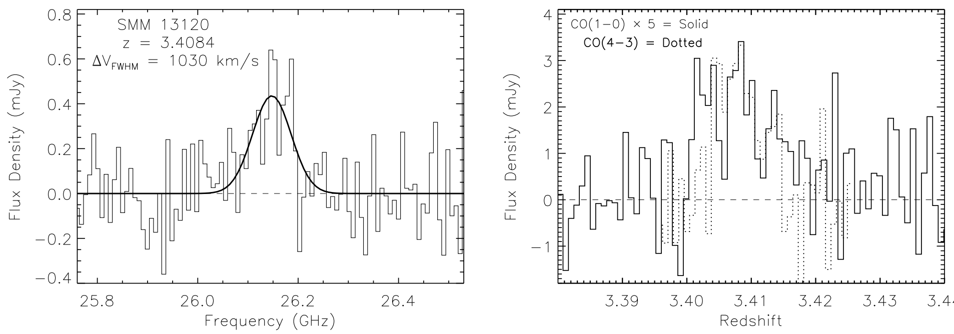

Figure 1. Left: baseline-subtracted CO(1→0) spectrum of SMM 13120. The spectrum has been boxcar-smoothed to a velocity resolution of $94\,\mathrm{km\,s^{-1}}$. A Gaussian fit to the line is overplotted as the thick curve. Right: comparison of CO(1→0) (solid line) and CO(4→3) spectra (dotted line). The spectra are smoothed to $58\ \mathrm{km\,s^{-1}}$, and the amplitude of the CO(1→0) spectrum has been multiplied by a factor of 5.

at $z = 3.408$, with $\Delta v_{\mathrm{FWHM}} = 530 \pm 50\,\mathrm{km\,s^{-1}}$ and $S_{\mathrm{CO}}\,\Delta v = 1.7 \pm 0.3\,\mathrm{Jy\,km\,s^{-1}}$. Assuming a H_2 to CO conversion factor $\alpha = 0.8\,M_\odot\,(\mathrm{K\,km\,s^{-1}\,pc^2})^{-1}$, this yields a molecular gas mass of $M(\mathrm{H_2}) = (4.2 \pm 0.7) \times 10^{10}\,M_\odot$, and a lower limit on dynamical mass $M_{\mathrm{dyn}} > 1.2 \times 10^{11}\,M_\odot$. SMM 13120 is unresolved in the $6\farcs9 \times 4\farcs8$ beam, so no information on the spatial structure of the molecular gas is available.

In our GBT observations of SMM 13120, we detect CO(1→0) emission centered at $\nu_{\mathrm{obs}} = 26.1481\,\mathrm{GHz}$, or $z = 3.408 \pm 0.004$, the first CO(1→0) detection from a SMG. In the left panel of Figure 1 we show our calibrated spectrum, smoothed from its velocity resolution of $4.478\,\mathrm{km\,s^{-1}}$ to $94\,\mathrm{km\,s^{-1}}$. The Gaussian fit overplotted in Figure 1 shows a wide line, $\Delta v_{\mathrm{FWHM}} = 1030 \pm 120\,\mathrm{km\,s^{-1}}$. Integrating over the line, we find $S_{\mathrm{CO}}\,\Delta v = 0.42 \pm 0.03\,\mathrm{Jy\,km\,s^{-1}}$. Applying the relations for L_{CO} and L'_{CO} presented in Solomon, Downes, & Radford (1992), this corresponds to a CO luminosity of $L_{\mathrm{CO}} = 1.0 \times 10^7\,L_\odot$, or $L'_{\mathrm{CO}} = 2.0 \times 10^{11}\,\mathrm{K\,km\,s^{-1}\,pc^2}$.

3.1. Comparison to CO(4→3) Observations

Mass estimates from CO line flux. From our GBT observations, we can estimate both the H_2 mass and the dynamical mass of the system. Downes & Solomon (1998) find a H_2 mass to CO luminosity conversion factor $\alpha = 0.8\,M_\odot\,(\mathrm{K\,km\,s^{-1}\,pc^2})^{-1}$ for nearby ULIRGs, most appropriate for regions of warm, moderately dense gas. Using this conversion factor, we find $M(\mathrm{H_2}) = 1.6 \times 10^{11}\,M_\odot$, a factor of ~ 4 greater than that implied by the CO(4→3) observations. Thus, the CO(4→3) emission likely does not trace the total mass/population of molecular gas in the galaxy. This comes as a surprise, as compared with other high-z objects detected in CO(1→0). PSS J2322+1944, APM08279+5255, and 4C60.07 are QSOs and a radio galaxy, with roughly similar masses derived from higher-J and lower-J transitions, leading to the conclusion that the higher-J transitions effectively trace both cold and warm gas

(Papadopoulos et al. 2001; Carilli et al. 2002; Greve et al. 2004). Such a conclusion seems not to apply to at least this single SMG.

We can use our estimate of $M(\mathrm{H_2})$ from CO(1→0) to calculate a rough gas-to-dust ratio for SMM 13120, using the 850 μm continuum detection. If we assume the locally measured κ_{850} found by James et al. (2002), scaled by $\nu^{1.5}$, and use the dust temperature found by Chapman et al. (2005), we obtain a dust mass $M_\mathrm{d} \sim 6\times10^8\,M_\odot$. The resulting gas-to-dust mass ratio is $\sim 4\times10^{-3}$, which is similar to the Milky Way ratio ($\sim 10^{-2}$) considering the possibly significant systematic errors in our calculation (see Blain et al. 2002).

To estimate the importance of the molecular gas mass relative to the total mass of the system, we estimate the dynamical mass, assuming the CO(1→0) emission comes from a single disk of radius 0.″5, the median CO source size for SMGs found by Tacconi et al. (2006). In Keplerian rotation the line width we find from our observations implies a dynamical mass $M_\mathrm{dyn}\sin^2 i = 1.6\times10^{11}\,M_\odot$, the same as $M(\mathrm{H_2})$. Though our model (and therefore dynamical mass) may be incorrect, the cold, diffuse component clearly contributes significantly to the total mass of the galaxy, and a large fraction of the mass of SMM 13120 is in molecular form. This SMG is thus likely to be still in the early stages of formation, yet to form much of its stellar mass.

Line profiles. We compare the CO(1→0) and CO(4→3) spectra (Greve et al. 2005) in the right panel of Figure 1, smoothed to approximately the same velocity resolution, with the amplitude of the 1→0 spectrum multiplied by a factor of five for ease of comparison. The low signal-to-noise (S/N) ratios of both spectra preclude detailed comparison; however both emission lines have similar shapes. Intriguingly, the 1→0 line appears clearly wider than the 4→3 line.

It is unclear why the lower-excitation line is wider than the higher-excitation line, considering that for nearby galaxies, the line profiles of multiple CO transitions tend to be similar (e.g., Yao et al. 2003). The difference may simply be an artifact of the low S/N of one or both spectra; however, if the multiple peaks seen in the 1→0 profile are real, they could arise from a rotating disk or a merger (Tacconi et al. 2006). We can try to interpret the differences in line profiles between the two transitions in terms of these scenarios. A single-disk scenario seems unlikely, as in a disk model, the rotation curve of the galaxy probably flattens away from the center of the galaxy. Hence, even if the warmer gas traced by CO(4→3) emission comes from a spatially distinct region from the cold gas, the line profiles would look similar — any outlying gas would have the same velocity as gas closer in. Alternatively, if the galaxy system is a merger of several components, the CO(1→0) line profile could be different from the CO(4→3) profile if the merging components possess different excitation levels. Thus, the interaction/merger of several components scenario better fits our observations. If true, such a finding would be significant, since it would indicate that SMM 13120 may be in the earliest stages of a merger: simulations by Mihos & Hernquist (1996) indicate that gas funnels into a central disk very rapidly during a merger, and we do not yet see this central disk.

CO line ratios and gas excitation. With detections in multiple CO lines, we can constrain the global temperature and density of the gas in SMM 13120. Having only two lines is generally not enough to place strong constraints on

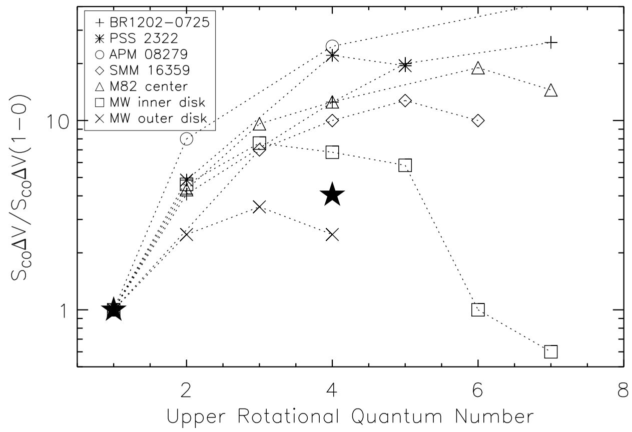

Figure 2. CO line SEDs (after Weiß et al. 2005) for high-z galaxies and local templates, normalized to the integrated CO(1→0) flux. The data points for SMM 13120 are the filled stars.

the excitation; however, since one of the lines is from the 1→0 transition, we can place strong lower limits on the column and number density of CO, and by extension, on the density of H_2.

Defining r_{43} as the ratio of the average brightness temperature of the CO(4→3) and CO(1→0) lines, we find $r_{43} = 0.26 \pm 0.05$ for SMM 13120. A standard large velocity gradient (LVG) code with local velocity gradient $dv/dr = 1\,\mathrm{km\,s^{-1}\,pc^{-1}}$ and all other parameters free to vary gives the following best-fit model: $[\mathrm{CO/H_2}] = 10^{-4}$, $T_{\rm kin} = 67\,\mathrm{K}$, and $n(\mathrm{H_2}) > 300\,\mathrm{cm^{-3}}$. If we constrain the $[\mathrm{CO/H_2}]$ abundance to be 10^{-5} and the kinetic temperature, $T_{\rm kin} = T_{\rm d} = 47\,\mathrm{K}$, we obtain a slightly higher limit $n(\mathrm{H_2}) > 10^3\ \mathrm{cm^{-3}}$. In contrast, the lower limits on the cold gas density implied by previous high-z CO(1→0) detections are nearly an order of magnitude larger, $n(\mathrm{H_2}) > 10^3 - 10^4\ \mathrm{cm^{-3}}$ (Papadopoulos et al. 2001; Carilli et al. 2002; Greve et al. 2004). Perhaps this is not surprising, since the value of r_{43} we find for SMM 13120 is significantly lower than those previously found (0.7–1.5). Thus, it is possible that SMM 13120 has a lower average gas density than the QSOs. Such diffuse, warm, and low-excitation gas has been observed in local ULIRGs (Solomon et al. 1997), though not yet at high redshift. Also, it is interesting to note that our density limits imply small upper limits on the radius of SMM 13120 in the range 0.9–1.4 kpc, assuming the galaxy is a uniform-density sphere, consistent with the median upper limit on size found by Tacconi et al. (2006).

To examine the excitation of SMM 13120, we plot in Figure 2 the integrated line luminosities for different CO lines, normalized to CO(1→0), for several high-z CO sources and several local template galaxies (for SMM J16359+6612, which has no CO(1→0) detection, we use the the CO(1→0) flux implied by the LVG fit from Weiß et al. 2005). Assuming all the CO emission comes from a single object, SMM 13120 is different from the others, somewhat between the inner disk and the outer disk of the Milky Way. The CO line SED of the Milky Way turns over at lower J than the other sources in part because of significant sub-thermal excitation. The similarity of SMM 13120 to the Milky Way disk suggests that sub-thermal excitation is also important in the SMG. If this is generally true, then observations of high-J emission lines provide only a lower limit on the molecular gas mass.

However, if we are dealing with a system of several interacting objects, it would significantly affect the implications of our observations.

3.2. Continuum-to-Line Ratio and Star Formation Efficiency

To investigate the evolutionary progression of SMM 13120 and other SMGs, we can estimate the efficiency with which molecular gas is converted to stars from the continuum-to-line ratio $L_{\rm FIR}/L'_{\rm CO}$, which does not depend on the CO-to-H_2 conversion factor. Using the value of $L_{\rm bol}$ from Chapman et al. (2005) for $L_{\rm FIR}$, and assuming all of the CO(1→0) emission comes from a single object, we find an upper limit to the $L_{\rm FIR}/L'_{\rm CO}$ ratio of $\sim 100\,L_\odot\,({\rm K\,km\,s^{-1}\,pc^2})^{-1}$, significantly less than the value ($\sim 400\,L_\odot\,({\rm K\,km\,s^{-1}\,pc^2})^{-1}$) obtained with the $J = 4 \rightarrow 3$ line.

Yao et al. (2003) find a median value of $L_{\rm FIR}/L'_{\rm CO}$ for LIRGs of $50 \pm 30\,L_\odot\,({\rm K\,km\,s^{-1}\,pc^2})^{-1}$, while Solomon et al. (1997) obtain a median value for ULIRGs of $160 \pm 130\,L_\odot\,({\rm K\,km\,s^{-1}\,pc^2})^{-1}$. The high-$z$ QSOs and radio galaxy with CO(1→0) detections have continuum-to-line ratios $L_{\rm FIR}/L'_{\rm CO} \sim 200 - 300\,L_\odot\,({\rm K\,km\,s^{-1}\,pc^2})^{-1}$ from the CO(1→0) line, which is significantly larger than that of SMM 13120. Also, for the QSOs and radio galaxy, similar values of $L_{\rm FIR}/L'_{\rm CO}$ are obtained using either the 1→0 transition or a higher-J emission line, unlike in SMM 13120. Thus, the star formation efficiency in SMM 13120 is more like those of local star-forming galaxies than those of the other high-z systems.

It seems the physical conditions in the ISM in SMM 13120 differ from those of the high-z QSOs and radio galaxy. Several possibilities could explain the different conditions. One is that there is simply more cold gas in SMM 13120 than in the QSOs. The optically and radio-selected high-z galaxies could also have a significant contribution to $L_{\rm FIR}$ from the AGN, reducing the star formation efficiency implied by the continuum-to-line ratio. The puzzle will not be easy to solve without more data, and we cannot draw conclusions about the SMG population as a whole without a larger sample. The new Ka-band correlation receiver at GBT should make this job easier to carry out, since the Ka-band receiver will cover the frequency range to which CO(1→0) is redshifted for galaxies in the range $2 < z < 3$, the range in which most SMGs lie.

4. Summary

We report the first detection of CO(1→0) emission from a SMG using the GBT. SMM 13120 contains more cold, diffuse gas than is indicated by its CO(4→3) line, and the cold gas appears to have a significantly greater velocity dispersion than the higher excitation gas. Assuming the CO emission comes from a single source, the gas excitation conditions in SMM 13120 are more like those in the Milky Way disk than those in other high-z objects. We look forward to learning the spatial distribution of the CO(1→0) and CO(4→3) source(s), from CARMA, EVLA, or ALMA, to determine if SMM 13120 is a single galaxy or a merging system of several galaxies, to explain our observations.

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Discussion

Hughes: You have shown the large velocity width of the CO(1–0) detection by the GBT and the anomalously low CO(4–3)/(1–0) ratio. Is it possible that the CO(4–3) observation, given the $\sim 1000\,\mathrm{km\,s^{-1}}$ line width, had sufficient bandwidth to accurately measure the baseline? An upward correction of the CO(4–3) line strength would bring the 4–3/1–0 line ratio into agreement with other high-z sources.

Hainline: The CO(4–3) data come from the Plateau de Bure interferometer, and the data from interferometers do not generally suffer from baseline shapes in the way that single-dish data do. Any offset from zero should be due to continuum emission. The lack of bandwidth in the CO(4–3) line could make it difficult to estimate the continuum level in the spectrum. In the cases where there is some continuum emission present that did not get removed from the spectrum, we would be over-estimating the line flux. However, this scenario appears unlikely at the currently achievable sensitivity level, because as yet SMGs seem not to be continuum sources at 3 mm.

Chapman: The radio emission appears to be spatially extended. This is interesting relative to the 4–3/1–0 findings.

Hainline: I agree.

Wilson: What is the mass obtained from FIR and submm dust continuum?

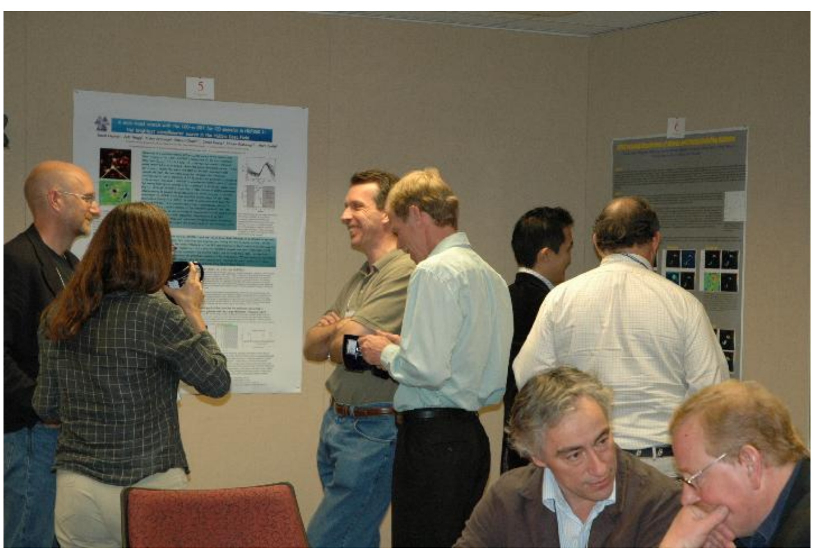
Hainline: For SMM 13120: $M_{\rm dust} = 2.7 \times 10^8 M_\odot$ assuming $\kappa_{200} \sim 1.5\,{\rm m^2\,kg^{-1}}$ (from local observations), $T_{\rm d} = 47\,{\rm K}$, $\beta = 1.5$; local universe method of dust mass calculation and $S_{850\,\mu{\rm m}} \rightarrow S_{200\,\mu{\rm m}}$ at $z = 3.4$ (or $5.8 \times 10^8 M_\odot$ if we use locally measured $\kappa_{850\,\mu{\rm m}}$ scaled by $\kappa_\nu \sim \nu^{1.5}$). With $M({\rm H_2}) = 1.6 \times 10^{11}\,M_\odot$, we get $M_{\rm dust}/M_{\rm gas} \sim 0.004$.

Hibbard: This is really a question for Axel Weiß. We have seen Axel's plot for the overlap region in the Antennae galaxies. Would we expect a J-excitation diagram similar to SMM 13120 if you include all the low-density gas in the Antennae (i.e., assuming the CO(3–2) gas in the Antennae was confined mostly to the region already mapped)?

Weiss: Looking at the CO(4–3)/CO(1–0) line ratios in SMM 13120 shown by Laura, it looks indeed like this source has a similar excitation as the overlap region of the Antennae. For both sources, however, only a few CO lines have been observed and more data are needed to answer this question.

Menten: Question 1: What software did you use to reduce your spectra? Question 2: Is it really necessary to use `aips++` to reduce single-dish spectra? Why does NRAO not just install the IRAM CLASS program?

Hainline: Answer 1: I used `aips++/DISH`, as well `GBTIDL` and scripts that I wrote for the tasks in Glish and IDL. Answer 2: It is not necessary to use `aips++` to reduce single-dish spectra. Re NRAO installation of CLASS: this is not a question I can answer!



David Hughes and Itziar Aretxaga talk to Richard Prestage and Neal Erickson; Daisuke Iono and Al Wootten discuss ALMA simulations; Pierre Cox confers with Reinhard Genzel.